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SENSORY PROPERTIES OF EXTRUDED CORN MEAL RELATED TO THE SPATIAL DISTRIBUTION OF PROCESS CONDITIONS

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ABSTRACT

The quality determining factors of extruded products are affected by the temperature, shear and pressure generated by any input to the extruder during the short residence time (< 120 s). Although the relationship of process history to measurable product qualities has been established, sensory qualities have not been well correlated to these process responses. Sensory attributes of extruded corn meal products were investigated and correlated to measured physical properties in this study. Corn meal was extruded in a twin screw extruder (Baker Perkins MPF 50/25; LD ratio 15:1) with step increases in screw speed from 200-400 rpm, and moisture from 16-22%. Principal component analysis (PCA) of main factors from sensory color, crispness, and adhesiveness was correlated to process torque, pressure and temperature. Spatial distribution of process response and product attributes showed crispness to be dependent on extrusion temperature. Porosity and adhesiveness were not correlated to any measured process response. PCA analysis identified significant differences in the effects of moisture and screw speed input to the extruder on product properties.

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INTRODUCTION

The Extruder is a versatile cooker; though difficult to model and control due to system interactions, it is used to produce a variety of products. Full understanding of the process is made difficult because of the coupled effect of most input to the process and the natural drift from set-points leading to instabilities. The three modules of the extrusion process illustrated in Fig. 1, are the process input, process response, and the product quality response. System analysis and multiple regression analysis have been used to describe the inter-connections of the process, yet simple first order models are used routinely to model the responses, making possible a direct relationship of process response to product quality response (Meuser *et al.* 1987; Richburg and Garcia 1988).

The quality of expanded products is determined by extrusion process responses (torque, pressure and temperature) encountered by the dough during the short residence time. Perceived sensory attributes such as crispness and rheological properties such as compression, correlate highly with extrusion temperature and shear history. The extrusion process imparts quality enhancing physical characteristics, thus making the expanded snacks readily acceptable (Maurice *et al.* 1976).

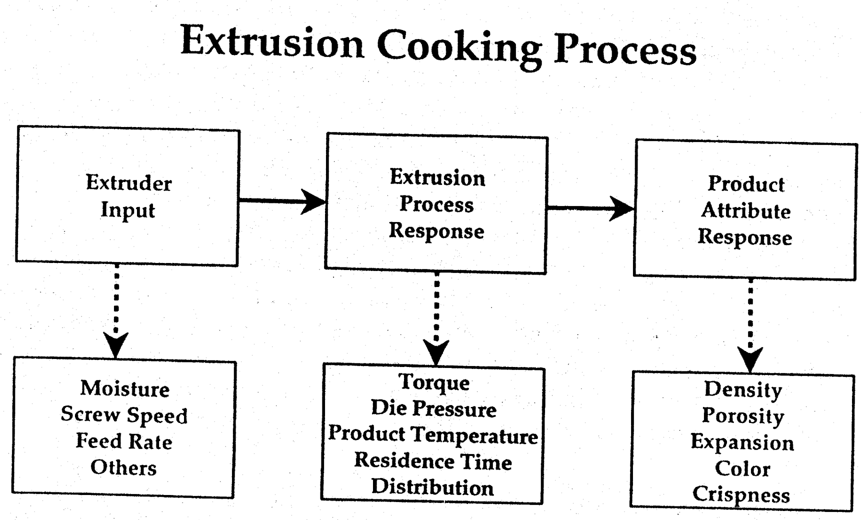

FIG. 1. SCHEMATIC ILLUSTRATION OF THE EXTRUSION PROCESS, SHOWING THE SYSTEMIC INFLUENCE OF INPUT TO THE EXTRUDER ON THE EXTRUSION PROCESS RESPONSE AND PRODUCT ATTRIBUTES

Modification of corn texture by extrusion improves taste and appearance (Gomez *et al.* 1983; Janssen 1986; Skierkowski *et al.* 1990). Product quality described by sensory characteristics such as crunchiness, adhesiveness, and color, is known to correlate with texture (breaking strength) in other products (Brady *et al.* 1985; Katz and Labuza 1981; Lee *et al.* 1987).

Principal component analysis (PCA) is a multivariate analytical tool that helps establish interrelationships of a set of variables. The principal components are linear combinations of factors of the original variables that are orthogonal to one to another. The spatial location of objects can be interpreted based on the factor loadings (Resurreccion 1988; Powers 1988).

The "acceptance" factor can be incorporated into the extrusion cooking process by relating sensory perception to instrumental measurements. The communality of sensory attributes of extruded corn products to measured physical properties of expanded corn was investigated in this study.

MATERIALS AND METHODS

Extrusion

Yellow corn meal purchased from a distributor (Lauhoff, Danville, IL), 11% (wet basis), was adjusted to the desired moisture content by direct water injection during extrusion. A Baker-Perkins MPF 50/25, 28 kW, co-rotating, intermeshing, twin screw extruder with smooth barrels and temperature control was used to expand the corn. All experiments were carried out with corn meal from the same lot. Temperatures in the cooking zones were set at 121.1C, 93.33C, 121.1C, and 121.1C. The corn was conveyed into the extruder with a volumetric feeder (K-tron Corp., Pitman, NJ), at the rate of 45.4 kg/h. A variable speed positive displacement pump was used to add water at the rate of 3.87 kg/h. Step increases in screw speed (rpm) from 200 to 400 rpm and moisture from 19 to 22%, were made in an orderly manner (low to high) to avoid destabilizing the extruder. A $2 \times 3 \times 3$ factorial design was completed and replicated 2 times. Three samples were taken for each treatment. Residence time distribution (RTD) was determined by pulsed input of one gram of red dye (FD&C #40) into the extruder when steady state conditions were established. Mean residence time was calculated from extrudate samples collected at 15 s intervals for 5 min.

The screw profile and configuration used were reported by Onwulata *et al.* (1992a).

The steady state process response data and physical attributes were analyzed by Principal Component Analysis (PCA) using Proc FACTOR and Proc SCORE of the SAS System. Components with eigenvalues greater than one were retained as principal factors. Significant correlations among variables were determined by the SAS subroutine Proc CORR (SAS Inst. 1989).

Sensory Analyses

Ten panelists (volunteers) were trained to identify and evaluate crispness, adhesiveness, yellowness and brownness using unstructured line scaling. Crispness was determined as the perceived relative force used in crushing the puffed corn between two fingers (CBH) and by crunching the puffs in the mouth (CBM). Adhesiveness was determined by feeling the stickiness of the puffed corn when held in the mouth for 10 s. As the material wets with saliva it becomes sticky and gummy. All other evaluations were performed in individual booths under red lights. Yellowness and brownness (visual attributes based on the amount of puffing and browning due to heat and pressure) evaluations were performed on samples placed in a Macbeth box with a 7400K light source (Macbeth, Baltimore, MD). The same panelists repeated the sensory test 4 times for each treatment.

Bulk Density

Bulk density was calculated as weight (g) of extruded corn collected in a plastic container, divided by the volume (2.1 cm^3). A mean of three readings was determined for each treatment.

Expansion

The longitudinal and radial expansion of extrudates was measured with a digital Vernier caliper (Mututoyo Corp., Japan). Expansion was determined by taking mean values of 25 samples of every replication within a treatment.

Porosity

Porosity was calculated from data derived from density determinations. Substance density of ground samples was determined with an air pycnometer, while particle density was determined as the space occupied by the extrudates with interspaces and void surfaces filled with sand (Onwulata 1991).

$$Porosity\ (\epsilon) = [1 - \frac{(\rho_p)}{(\rho_s)}] \times 100 \qquad (1)$$

where ρ_p = particle density in kg/m^3, ρ_s = substance density kg/m^3 and ϵ = porosity (%), (Payne *et al.* 1990).

Color

Twenty grams of puffed corn samples were blended for 20 s in a Waring Blendor and sieved with a 2 mm sieve. Particles less than 2 mm in size were used for color determinations. A Hunterlab colorimeter model D25-PC2(Δ) (Hunter Assoc. Lab., Reston, VA), with a D25 L optical sensor was used. Lightness (Δl), redness (Δa) and yellowness (Δb) values were determined and total color difference (ΔE) was calculated (Manoharkumar *et al.* 1978).

$$\Delta E = \sqrt{(\Delta l)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{2}$$

RTD samples were collected at 15 s intervals for 5 min, ground in a Waring Blendor and then sieved through a 2 mm mesh screen. Total color difference and the "a" values were used to estimate mean residence time ($\bar{t}$), where $\bar{t}$ = mean residence time; (Δa) = redness value of extrudate at discrete time Δt_1.

$$\bar{t} = \frac{\sum_{i=1}^{\infty} (t_1 . \Delta a . \Delta t_1)}{\sum_{i=1}^{\infty} (\Delta a . \Delta t_1)} \tag{3}$$

RESULTS AND DISCUSSION

Extrusion Conditions

The object plot of the principal component analysis (Fig. 2) shows retained principal factors for the step rpm and moisture input to the extruder. The relative positions of the treatments on the two-dimensional plot are based on the coordinates of their principal factor scores. Treatment groupings were well defined for high (400) and low (200) rpm, as well as for high (22%) and low (16%) moisture. This polar arrangement is supported by measured process responses and product quality attributes that correlate with the placement. Linear placement of input conditions on the plane shows that reported linearity in extruder response to rpm and moisture is a function of the input. Treatments with intermediate moisture (19%) and shear (300 rpm) were placed in the middle of the plane. The intermediate region coincides with reported areas of instability in the extrusion process (Roberts and Guy 1986). Moisture and screw speed changes are important external inputs into the extruder as they affect product texture. High moisture interferes with dough expansion by reducing

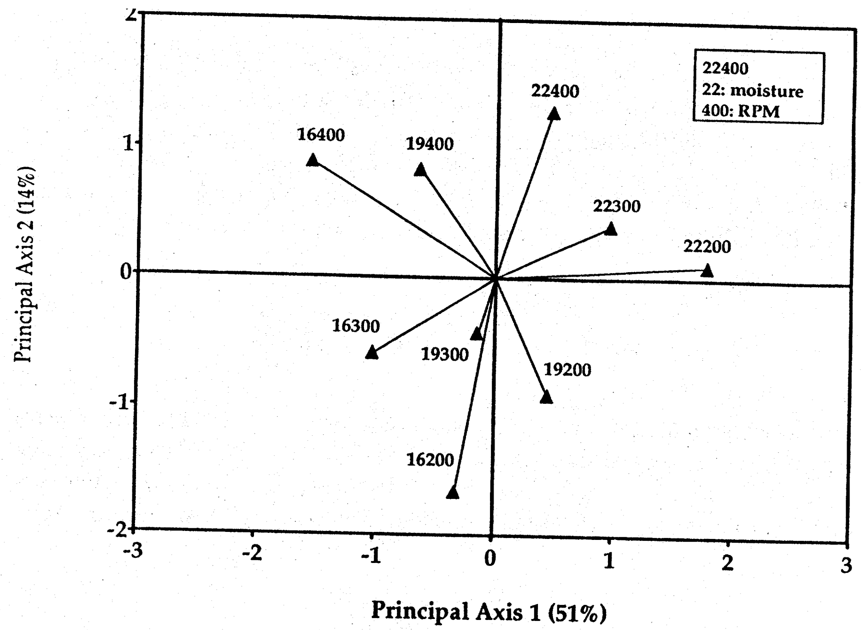

FIG. 2. PRINCIPAL COMPONENT ANALYSIS OF EXTRUDER PROCESS INPUT: PLOT OF PRINCIPAL FACTORS OF MOISTURE AND SCREW SPEED INPUT

shear and temperature which affects puffing, leading to increased breaking strength and reduced crispness (Onwulata *et al.* 1992b). High shear stress has been linked to lower sensory scores for crispness (Skierkowski *et al.* 1990). The effect of simultaneous increase of moisture and shear on product quality is to increase shear and temperature and lower acceptance. PCA shows that the underlying structure of the interactions of moisture and rpm input could be predetermined on the basis of the polar alignment.

Extruder Response

Process response (torque, die pressure, product temperature and die temperature) show two distinct cluster groups (Fig. 3). Torque and die pressure responses were associated with principal axis 1, while product temperatures were associated with axis 2. Temperature responses were different from torque and die pressure showing that the two affect different product attributes. Regression of process response to product quality indicates significant dependency of quality attributes on temperature, but not on torque or die pressure. An increase in product temperatures correlated with an increase in

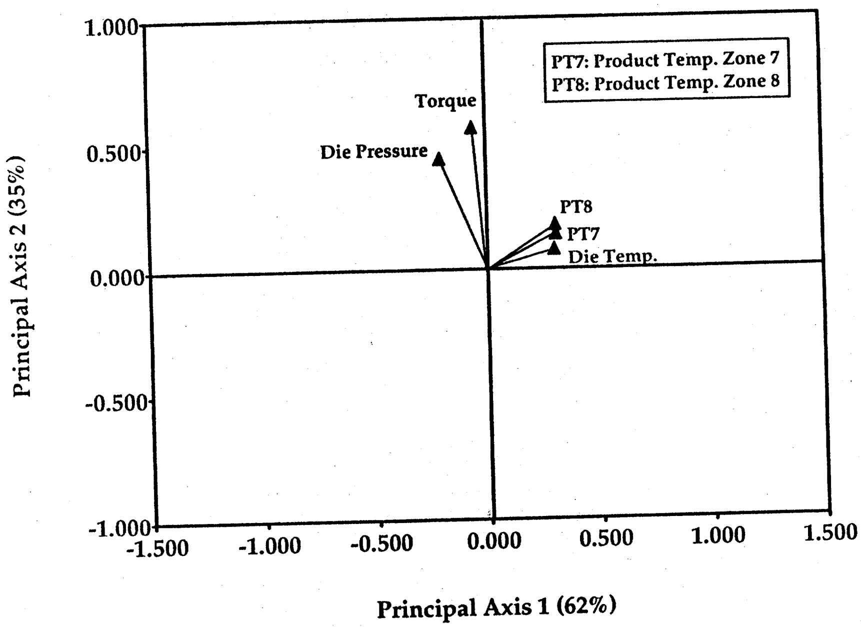

FIG. 3. PLOT OF THE PROCESS RESPONSE TORQUE, PRESSURE, AND PRODUCT TEMPERATURE (PT7 & PT8), IN THE PLANE DEFINED BY THE FIRST AND SECOND PRINCIPAL AXES

density (R^2=0.85), and a decrease in porosity (R^2=0.65). Others have reported similar results when process responses were modeled by different techniques (Kirby 1988; Tayeb *et al.* 1989; Richburg and Garcia 1988).

An overlay of PCA plots of process response and product quality would show that color values, density and breaking force are associated with product temperature. This confirms the direct dependence of quality on process temperature. Torque and die pressure seem to influence only radial expansion. While radial expansion may be associated with die pressure, porosity is not directly related to any process response, explaining the known difficulty in modeling radial expansion and porosity based on process temperature functions (Padmanabhan and Bhattarcharya 1989).

Product Quality

Spatial representation of measured quality attributes by PCA show significant ($P < .01$) differences in product quality (Fig. 4). Product density and breaking force were clustered, showing correlation of textural characteristics.

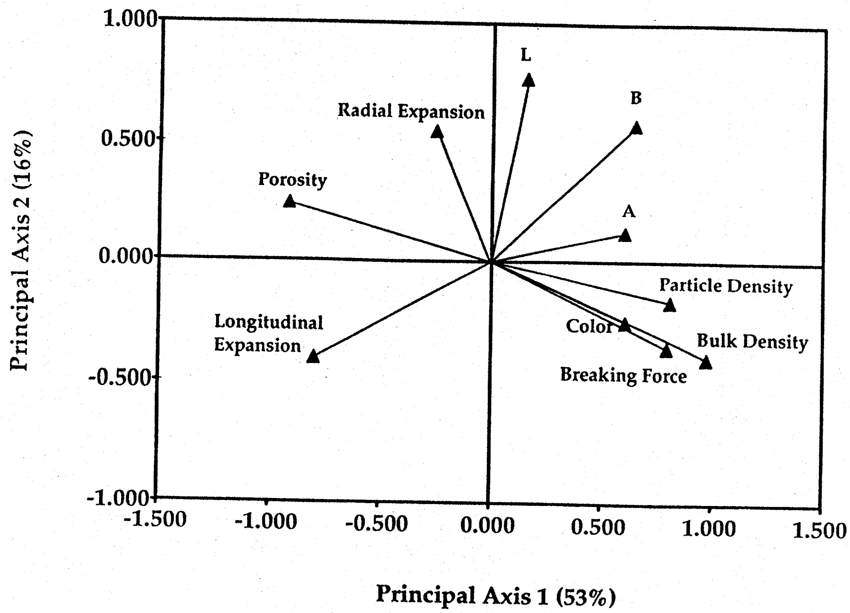

FIG. 4. PLOT OF THE MEASURED QUALITY ATTRIBUTES LOADINGS IN THE PLANE DEFINED BY THE FIRST AND SECOND PRINCIPAL AXES

Color values L, A, and B were in the same quadrant; but total color difference (ΔE) was different, showing that ΔE measures an entirely different attribute. Radial expansion was diametrically different from longitudinal expansion, while porosity was not associated with either radial or longitudinal expansion. Particle density ($R^2=0.87$), and shear force ($R^2=0.83$), were positively correlated with temperature, while longitudinal expansion ($R^2=0.71$) and porosity ($R^2=0.65$) were negatively correlated. A direct relationship exists between process response and sensory attributes, except for adhesiveness which was influenced by torque and die pressure. To predict product acceptance, all process responses must be accounted for in the model. Specific mechanical energy calculated from extruder screw speed, torque, feed rate and power rating is such a model, and has been shown to predict product quality accurately (Onwulata *et al.* 1992b; Lengerich 1990; Kirby 1988).

Sensory Analyses

Crispness, adhesiveness and sensory color attributes analyzed by PCA are shown in Fig. 5. Differences in sensory attributes among the treatments were significant for crispness, adhesiveness ($P < .05$), and yellowness, brownness

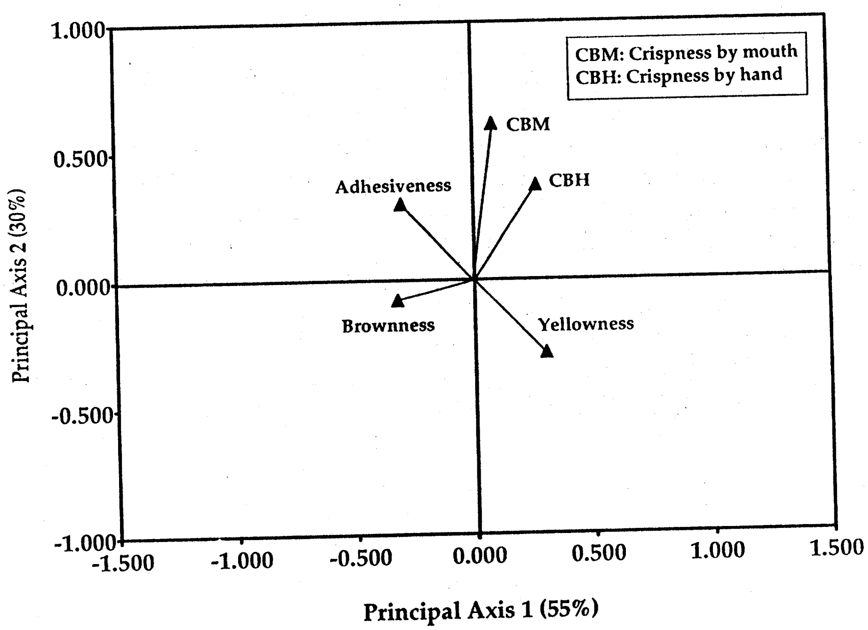

FIG. 5. PRINCIPAL COMPONENT ANALYSIS OF SENSORY EVALUATIONS OF EXTRUDED CORN MEAL: PLOT OF PRINCIPAL FACTORS FOR CRISPNESS (CBM & CBH), ADHESIVENESS AND COLOR

($P < .01$). Crispness means measured by CBM and CBH were similar as their principal factors were clustered. Other attributes such as yellowness, brownness, and adhesiveness were different from crispness. Crispness was negatively correlated with brownness ($R^2=0.63$), and positively correlated to product temperature ($R^2=0.98$). Longitudinal expansion correlated negatively with radial expansion ($R^2=0.71$). As expansion increased, crispness decreased. Comparison of the factor pattern plots for sensory analyses and instrumental measurements of product quality shows that adhesiveness may be influenced by porosity. Crispness is correlated to color values (L, A, B), all of which are affected by dough temperature during extrusion cooking. Skierkowski *et al.* (1990) reported a lowering of sensory scores for crispness with increasing shear but an increase in crispness score with increasing temperature. Our results show the positive effect of increasing temperature on crispness until the product starts to brown (loss of yellowness); then crispness is adversely affected.

Quality Assessment

The colorimetric values of the mean RTD of expanded corn are presented in Fig. 6. As screw speed increased, the residence time decreased. Significant ($P < .05$) differences in mean residence distribution pattern were observed. As indicated by the planer location of color values and ΔE (Fig. 3), a disparity also existed in the estimation of mean residence time. Similarly, Hunter "A" (redness) values overestimated residence time. Similar results on the effects of screw speed have been reported by others (Lin and Armstrong 1988; Meuser *et al.* 1987). Changes in RTD are attributable to dough viscosity and conveyance within the barrel, which in turn are influenced by temperature profile and shear. Over-or under-estimation of residence time by 12-16 s for a process that lasts less than 100 s would create a significant acceptance problem. Peng (1991), reported that Hunter "A" values overestimated residence time by an average of 16 s when compared to the dye concentration method. Total color difference (ΔE), models product quality more closely.

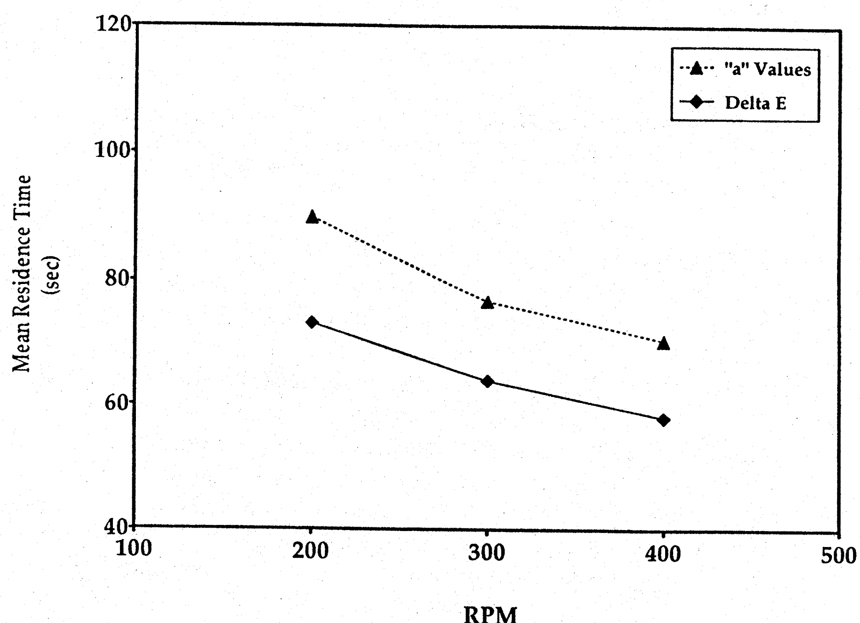

FIG. 6. MEAN RESIDENCE TIME DISTRIBUTION OF PUFFED CORN MEAL AT 19% MOISTURE: TOTAL COLOR DIFFERENCE (ΔE) AND HUNTER "A" VALUES

CONCLUSION

Process temperature had the strongest influence on the quality of the final product. Temperature was significant in affecting the textural characteristics, especially breaking strength and crispness. PCA was useful in identifying relationships between process response and product quality, allowing for projections to be made on product acceptance. The spatial representation allowed for an easy visual association of correlated variables and interdependent variables. Fewer attributes can be selected from clustered groups to reduce the number of variables to be accounted for in state models. For instance, torque and product temperature could be selected to model extrusion process responses such as bulk density, longitudinal expansion, porosity, for instrumental quality evaluations,as well as CBM, yellowness and adhesiveness for sensory evaluation. Residence time distributions within the extruder affect simple colorimetric tests; however, total color difference predicted residence time better. Although the colorimetric method is simple and cost effective, using the Hunter "A" value alone tends to overestimate RTD.

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